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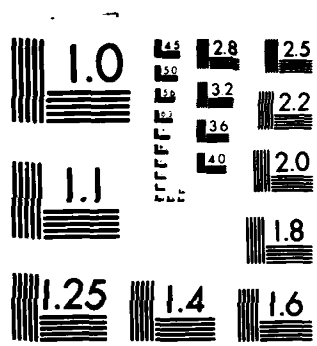

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ABSTRACTS OF

CONFERENCE ON MILITARY AND SPACE APPLICATIONS OF ROBOTICS

ADA 129666

AT NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.
November 3, 4, & 5, 1980

SPONSORED BY

OFFICE OF NAVAL RESEARCH &
THE NAVAL RESEARCH LABORATORY

PROGRAM

Monday - November 3, 1980

1. Registration.
8:30-9:00

2. Welcome.
Dr. James R. Slagle, NRL
Mr. Marvin Denicoff, ONR

3. Opportunities for Robotics Research.

Morning Session Chairperson - Mr. Marvin Denicoff

9:40-10:20 "New Directions in Space Automation"
Dr. William Gevarter, National Aeronautics & Space Administration

10:20-10:35 COFFEE BREAK

10:35-11:15 "Prospects for Advanced Automation in the Military"
Dr. Robert Kahn, Defense Advanced Research Projects Agency

11:15-11:55 "Battlefield Robots of the 21st Century"
Mr. Daniel Leonard, Naval Ocean Systems Center

11:55-12:35 "Some Applications & Limitations of Industrial Robots in Shipbuilding"
Mr. William Holden, Naval Material Command

12:35-2:00 LUNCH

Afternoon Session Chairperson - Dr. James R. Slagle

2:00-2:40 "The Concrete and Abstract Naval Applications of Robotics"
Mr. Scott Harmon, Naval Ocean Systems Center

4. Overview of Robotics Research.

2:40-3:20 "Overview of Robotics Research Issues"
Prof. Patrick Winston, Massachusetts Institute of Technology

3:20-3:35 COFFEE BREAK

5. Vision and Sensing Systems.

3:35-4:15 "Touch Sensing Technology: A Review"
Prof. Leon Harmon, Case Western Reserve University

4:15-4:55 "Stereopsis, Edge Detection, and the Perception of Surfaces"
Dr. Michael Brady, Massachusetts Institute of Technology

Tuesday - 4 November 1980

Morning Session Chairperson - Ms. Susan A. Bouchard

9:00-9:40 "Vision Systems for Robots"
Prof. R.J. Popplestone, Univ. of Edinburgh

9:40-10:20 "Object Recognition: Finding Figures That Approximate Given Points"
Dr. James R. Slagle, Ms. Susan A. Bouchard, Dr. John K. Dixon, Mr. William Kennedy
Naval Research Laboratory

10:20-10:35 COFFEE BREAK

10:35-11:15 "Robot Applications that Demand Sensory Perception"
Mr. Joseph Engelberger, Unimation

6. Manipulator Systems.

11:15-11:55 "Dexterous Robot Manipulation - A Computational Problem"
Dr. Marc Raibert, Jet Propulsion Laboratory

11:55-12:35 "A Study of Tendon Control and an Efficient Lagrangian Dynamics Formulation"
Prof. John Hollerbach, Massachusetts Institute of Technology

12:35-2:00 LUNCH

Afternoon Session Chairperson - Dr. Alan Meyrowitz

7. Integrated Programmable Reasoning Systems.

2:00-2:40 "Integrated Robots & Distributed Computing"
Dr. Jerome Feldman, Univ. of Rochester

2:40-3:20 "Integrated Robotic Systems"
Prof. Thomas Binford, Stanford University

3:20-3:35 COFFEE BREAK

3:35-4:15 "Spacial Reasoning"
Dr. Tomas Lozano-Perez, Massachusetts Institute of Technology

4:15-4:55 "A Survey of Robot Programming Languages"
Dr. Russell H. Taylor, Dr. David Grossman, Dr. Phillip Summers, International Business Machines Corp.

6:30 BANQUET - George Washington University
After dinner speaker - Prof. Marvin Minsky, Massachusetts Institute of Technology, "Future Directions in Robotics" At the University Club in the Marvin Center Building, 800 21st St. N. W.

Wednesday, 5 November, 1980

Morning Session Chairperson - Dr. John K. Dixon

9:00-9:40 "Technologies for Autonomous Systems"
Dr. Ewald Heer, Jet Propulsion Laboratory

8. Concepts for Future Applications.

9:40-10:20 "Semi-Autonomous Robots for Space & Military Applications"
Dr. Charles Rosen, Machine Intelligence Corp.

10:20-10:35 COFFEE BREAK

10:35-11:15 "Automated Underwater Vehicles"
Prof. Raj Reddy, Carnegie-Mellon University

11:15-11:55 "Towards the Factory of the Future"
Prof. Jerry Agin, Carnegie-Mellon University

11:55-12:35 "Intelligent Logistics Support Systems"
Prof. Mark Fox, Carnegie-Mellon University

12:35-2:00 LUNCH

Afternoon Session Chairperson - Mr. Marvin Denicoff

2:00-2:40 "Hierarchical Control Using 3-D Vision"
Dr. James Albus, National Bureau of Standards

2:40-3:20 "Underwater Robotics"
Dr. John K. Dixon, Ms. Susan A. Bouchard, Mr. William G. Kennedy, Dr. James R. Slagle
Naval Research Laboratory

3:20-3:35 COFFEE BREAK

3:35-4:15 "Robots & Shipbuilding"
Dr. David Nitzan, SRI International

4:15-4:55 "Some Comments on the Next 25 Years"
Dr. Jesco von Puttkamer, National Aeronautics & Space Administration

Integrated Robotic Systems

by

Thomas O. Binford
Artificial Intelligence Laboratory
Stanford University
Stanford, California

We will present descriptions of two systems which represent current and future integrated systems for robotics including motion, force sensing, perception, programming language, object models, and planning.

Stereopsis, Edge Detection, and the perception of Surfaces.

Dr. Michael Brady
MIT Artificial Intelligence Laboratory

The work of Marr, Poggio (Tuebingen), and Grimson of the MIT Artificial Intelligence Laboratory in developing a theory of stereo vision is described. The first stage of the work necessitated a revision of the theory of edge detection, proposed by Marr in (1976), resulting in the recent theory of Marr and Hildreth (1980). A real time hardware implementation of the edge detection theory is sketched. The application of the theory to motion computation is discussed. The second stage of the stereo work, developed by Grimson, concerns the problem of interpolating smooth surfaces from the dicrete set of sample points at which the disparity is computed explicitly. The interpolation work has been applied by Brady and Grimson to explain subjective contours.

UNDERWATER ROBOTICS

by

Dr. John K. Dixon
Ms. Susan A. Bouchard
Mr. William G. Kennedy
Dr. James R. Slagle

NRL has initiated a research project to establish a technical base for an underwater robot. This robot is of value for two reasons: it could operate in a hostile environment and it might be able to perform certain simple tasks more economically than a man.

The robot vehicle would be programmed at a base and proceed to its assigned destination at the bottom of the ocean. It would there work autonomously without communication from the shore. Therefore, its computer control system must provide some degree of intelligence. The robot must detect objects with suitable sensors, build up a computer map of its environment, recognize objects, plan actions to carry out the assigned task, recover from mistakes, and recognize when the assigned task is completed.

Some of the jobs that such a robot might do include:

- collecting ocean bottom rock and soil samples
- placing an instrument package on the sea floor, and later
- retreiving it
- finding lost objects and attaching lines for salvage assembly and adjustment and cleaning of undersea installations.

This project is concerned with software rather than hardware. Mark I is a simplified robot, a first cut at providing the minimal intelligence necessary for an underwater robot. Mark I was implemented and performed approximately as expected, successfully carrying out the tasks which it was assigned.

Naval Research Laboratory
Washington, D.C. 20375

Robot Applications that Demand Sensory Perception

by

J.F. Engelberger
Unimation, Inc.
Danbury, Connecticut

Deaf, dumb and blind robots are being used throughout industry at an accelerating pace. Nonetheless many jobs baffle insensate robots. The nature of the need will be discussed with reference to a number of disparate potential applications including:

arc welding
mechanical assembly
packaging chocolates
shearing sheep

To stimulate discussion, the paper will include outlines of sensory feedback concepts that Unimation Inc. is espousing to cope with these application challenges.

"Distributed Computing and Integrated Robotics"

by

Jerome Feldman
Computer Science Department
University of Rochester
Rochester, NY 14627

Distributed computing is concerned with the accomplishment of computational tasks by a large number of separate processes, often on a variety of separate processors. Somewhat surprisingly, the techniques for coordinating these separate processes in time-independent manner are quite like those needed to control a robotic device, which also has several independent tasks. The talk will survey how many of these common ideas developed in the opposite orders--early work in languages and systems for controlling robots have given rise to many key concepts in distributed computing. These should now be reapplied to robotics.

William B. Gevarter

NEW DIRECTIONS IN SPACE AUTOMATION

ABSTRACT

The current pace in electronics technology and computer science is stimulating rapid advances in automation and machine intelligence. To date, NASA activities in this area have been directed at specific applications such as planetary rovers. However, realization has set in that NASA's inability to obtain approval for such missions has been more determined by mission costs than by lack of technological feasibility. Estimates indicate that as much as 90% of a mission cost is involved with human productivity on the surface of the Earth, rather than with materials and fabrication of the spacecraft. Thus, NASA is reformulating its automation program first to address the issue of human productivity to reduce costs here on the ground, then to automate operations in space to relieve the load on ground operations and, finally, to provide advanced automation in space to afford new capabilities. Such capabilities can be intelligent outer loops for guidance and control, automated experiment control, automated information interpretation, and, in the future, an almost completely autonomous spacecraft. Longer range goals could include self sufficient, self-replicating automatons that can be used to begin exploration of the galaxies.

National Aeronautics & Space Administration
Washington, D.C. 20546

TOUCH SENSING TECHNOLOGY:

A REVIEW

by

Leon D. Harmon, Professor
Department of Biomedical Engineering
Case Western Reserve University
Cleveland, Ohio 44106

ABSTRACT

This is a survey and assessment of tactile sensing feedback devices and systems for robots. Special emphasis is placed on touch sensing as it relates to industrial manipulators. The state-of-the-art is surveyed in parameters (e.g., force, torque, compliance, slip), in transducers (e.g., conductive and semiconductive materials and arrays, non-contact sensing), and in tactile pattern recognition. Present application areas in manipulation and in prosthetics are outlined. This review concludes with consideration of outstanding problems, new opportunities, and emergent technology.

Concrete and Abstract Naval Applications of Robotics

by

S.Y. Harmon
Naval Ocean Systems Center
San Diego, CA 92152

"TECHNOLOGIES FOR AUTONOMOUS SYSTEMS"

Ewald Heer
Jet Propulsion Laboratory

ABSTRACT

Autonomous systems receive increasingly more attention within the space and military programs. Studies are being conducted to determine the types of systems that should be automated for greater effectiveness and the level of automation that can be achieved based on present and projected technology. It becomes important to determine also the implications that automation has on the trade-off between human and machine problem solving and decision making. This presentation focuses on some aspects of autonomous system technologies: (1) relevant technologies are discussed within the framework of an operational space system concept, (2) the state of these technologies is described with emphasis on advanced control theory, operations research, and artificial intelligence, (3) related work at the Jet Propulsion Laboratory is presented, and (4) critical technology needs are identified for future research.

Some Applications & Limitations of Industrial Robots in Shipbuilding

The presentation develops the case supporting a major new initiative in shipbuilding technology under the auspices of the Navy's Manufacturing Technology program. In this context the applications and limitations of industrial robots are discussed. After touching briefly on the importance of shipbuilding, the productivity problems of industry are examined with particular emphasis on the role of technology. The results of the Technology Survey of the US Shipbuilding Industry sponsored by the Maritime Administration are presented. Of particular note, the U.S. was found deficient on average in 51 of 70 shipbuilding technologies surveyed, and in 39 cases the best industrial practice was not found anywhere in this country. Industrial robotics is one of the opportunities being pursued to improve shipbuilding technology. Clearly, some applications are feasible now. However, the unique characteristics of shipbuilding such as size, weight, accuracy, lot size and fixed point construction dictate additional development in, respectively, the reach, load carrying, sensors and compliance, programming, and mobility of currently available industrial robots. These issues and potential applications are discussed.

William F. Holden
General Engineer
Manufacturing Technology Program Office
Headquarters, Naval Material Command

Dr. John M. Hollerbach
The Artificial Intelligence Laboratory
Cambridge, Massachusetts

Abstract

An efficient Lagrangian formulation of manipulator dynamics has been developed. The efficiency derives from recurrence relations for the velocities, accelerations, and generalized forces. The number of additions and multiplications varies linearly with the number of joints, as opposed to past Lagrangian dynamics formulations with an n^4 dependence. With this formulation it should be possible in principle to compute the Lagrangian dynamics in real time. The computational complexities of this and other dynamics formulations including recent Newton-Euler formulations and tabular formulations are compared. It is concluded that iterative formulations based either on the Lagrangian or Newton-Euler dynamics offer the best method of dynamics calculation.

Recently the MIT AI Lab has been exploring issues of tendon control, touch sensing, and dextrous hands. A prototype 3 degree of freedom tendon driven shoulder joint has been constructed. Reasons for constructing tendon driven manipulators are considered, including weight reduction, more degrees of freedom, and unique control strategies such as independent programming of force and compliance. The Laboratory is also engaged in the study and construction of more dextrous hands. On the way to building a multi-degree of freedom hand, a 4 degree of freedom tendon finger has been constructed. In a parallel development a high resolution touch sensor with spatial resolution of 256 points per cm^2 and rough force resolution has been developed. The tendon finger/touch sensor combination have been used to recognize objects by touch.

Battlefield Robots of the Twentyfirst Century

This talk will discuss a little of my background and some recent work. A concept of the battlefield circa 2000 will be presented and be used to justify the use of robots as combat tools. Sample tasks which might be suitable for accomplishment by robots and robot-like devices will be identified and described. Each task presented will require an increasingly complex robot in order to suggest a logical evolution of robot introduction into the battlefield. A non-exhaustive list of functional robot characteristics will be presented for accomplishment of each task. The tasks described will include command control functions, surveillance functions, logistics functions, and killing functions. Degrees of required technical complexity range from relatively simple to highly complex. My purpose is to stimulate ideas within the technical comunity and focus attention on valid combat problems.

by

Daniel Leonard
Naval Ocean Systems Center
San Diego, CA

ROBOTICS IN SHIPBUILDING

by David Nitzan
SRI International, Menlo Park, California

October 13, 1980

Application of robots to shipbuilding can increase labor productivity, improve working conditions, and prepare the nation for shipbuilding emergency. Such application requires efficient programming, sensor guidance, and computer control of robots and semiautonomous teleoperators. A recent study by SRI examines the technoeconomic and environmental incentives for using robots in welding, cutting, grinding, blasting, and paint-spraying tasks in shipbuilding. The study also presents conceptual designs of robotic stations for programming and performing these tasks.

Programming may be done in situ by manually leading either the robot itself or a separate measurement arm, or off-line by using CAD/CAM data base. Programming R&D issues include sensor utilization, modeling of shipbuilding processes, and development of computer expert systems for design and planning of these processes. Manual welding of 3D structures is the most labor intensive task in shipbuilding. Robotic arc-welding R&D issues include sensing joint position and gap (primarily with machine vision), servoing the torch and welding parameters, inspecting weld surface and interior, and achieving robot portability. Robotic cutting, grinding, blasting, and painting entail primarily development issues. Material flow and handling in a subassembly system incorporating robots is an important logistics issue in shipbuilding.

Planning Collision-Free Paths for Manipulators using Configuration Space

Tomas Lozano-Perez
MIT Artificial Intelligence Laboratory

Two major approaches to manipulator programming have been identified:

1. Explicit programming — in which the user specifies all the manipulator motions needed to accomplish a task.

2. Model-based programming — in which the user specifies geometric models of objects and a description of the task in terms of these models. The detailed manipulator motions are derived by the manipulator system from these specifications.

This talk discusses some of the central geometric problems that arise in the model-based approach to manipulator programming and suggests a solution approach. In particular, the problem of planning collision-free motions among obstacles will be discussed. The solution to this geometric problem is based on the following approach:

1. Characterize the position and orientation of the moving object as a single point in a Configuration Space, in which each coordinate represents a degree of freedom in the position and/or orientation of the object.

2. Compute the regions of Configuration Space representing the configurations forbidden to this object due to the presence of obstacles.

3. Find a path, i.e. a sequence of configurations, outside all of the *forbidden regions* of the Configuration Space.

The talk will present algorithms for computing the forbidden regions in Configuration Space when the moving object and the obstacles are polygons or polyhedra. An implementation of the algorithm for finding collision-free paths using the Configuration Space will be described. The application of the Configuration Space approach to other geometric problems will also be discussed.

R. J. Popplestone
Dept. of Artificial Intelligence
University of Edinburgh

The RAPT robot language is based on the idea of defining the behaviour of a robot by specifying relationships to be established between features of bodies. For example, one may specify that one plane surface is to be against another, or that a bolt is to fit a hole. Given the limited efficacy of existing machine vision systems, I am going to argue that the best approach to making a robotic system in the near future which can make some use of vision is to tie the visual capability closely to the body of knowledge existing about the world.

This can be expressed in a RAPT like language, and the sensory systems can be regarded as giving values to unbound variables resulting from incomplete world-specifications. It should be noted that the identification of a visual element such as an edge with a body feature creates a constraint of the same nature as that dealt with by RAPT itself. Thus a visual edge defines a plane in the world and an identification with an edge of a body implies the relationship that this edge is against the plane.

Dexterous Robot Manipulation: A Computational Problem

by

Marc H. Raibert
Computer Science Department
Carnegie-Mellon University
Pittsburgh, Pennsylvania

When research in manipulation and robotics began some 15 or 20 years ago the computing power available for allocation to a given task, and researchers' perceptions of how that availability would increase with time, had a profoundly conservative influence on the types of algorithms studied, the approaches taken, and even the paradigms of research that emerged. The VLSI revolution now makes those approaches and paradigms obsolete. In this talk I show how researchers and users in robotics, once freed from the mini-computer syndrome of the 70's by our new found source of cheap computing, can focus on techniques and developments that are innovative, but conceptually straightforward. Examples are given that touch on manipulator dynamics, force sensing, tactile sensing, and path planning.

MACHINE INTELLIGENCE CORPORATION

From: Charles A. Rosen
Machine Intelligence Corp.
Palo Alto, CA 94303

Abstract

Semi-Autonomous Robots for Space and Military Applications

The present state-of-the-art of third generation industrial robots will be reviewed, emphasizing the important role of sensory systems in achieving autonomous behavior that can cope with incompletely specified environments and unforseen events. The advantages of "marrying" advanced tele-operators (with man in the loop) with sensor-controlled industrial robots (autonomous after initial programming and training) will be explored in relation to space and military operations. By incorporating multi-sensory subsystems, performance will beyond the range of human sensory capabilities may be achieved. Further, it will be possible to "time-share" a trained human who can supervise several semi-autonomous robots, high-level decisions being reserved for the human. The concept of distributed manipulative systems composed of specialized semi-autonomous machines linked interactively with computer and humans will be briefly explored.

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Object Recognition: Finding Figures That Approximate Given Points

by

James R. Slagle
Susan A. Bouchard
John K. Dixon
William G. Kennedy

Naval Research Laboratory
Washington, D.C.

ABSTRACT

A system is proposed which, when given a list of points on the plane, will find a good figure which approximately passes through the points. (A rectangle recognizer has already been programmed and successful experiments have been performed with it, but this is the subject of another paper.) Some of the twelve figures considered are the line segment, curcle, parallelogram, and equilateral triangle. Many more than twelve figures can be handled because the system uses simple figure descriptions in terms of the degrees of freedom of a figure. The system searches a disjunctive (or) goal tree.

We are performing research needed in the development of a robot manipulator system. Object recognition is a very important part of the system. Although the robot will be sensing three dimensional objects from tactile or other sensors, there are reasons for first treating the two dimensional case.

Presented at the Conference on Military and Space Applications of Robotics, Washington, D.C., sponsored by the Office of Naval Research and the Naval Research Laboratory, November 1980.

"A Survey of Robot Programming Languages"

by

Russell H. Taylor
David Grossman
Phillip Summers

Computer Science Department

IBM T.J. Watson Research Center
Yorktown Heights, New York

During the past decade more than a dozen robot programming languages have been developed in various laboratories around the world. The survey of their characteristics reveals similarities and differences in syntax, symantics, user interface and underlying philosophy.

Patrick H. Winston

"Overview of Robotics Research Issues"

Abstract. To be comprehensive, a research effort in robotics must involve collaborating people doing research in the following areas:

Spatial Reasoning, Object Modelling, and Assembly Planning;
Compliance and Force Control;
Trajectory Control and Dynamics;
Sensor, Manipulator, and Hand Design; and
Visual Recognition, Inspection, and Guidance.

This overview will fix the state of the art in each area, propose research problems, and predict what can be done in five to ten years with an aggressive research program.

"Towards the Factory of the Future"

by

Prof. Jerry Agin

Carnegie-Mellon University

Although robots are currently being used in several types of manufacturing operations throughout the country throughout the world, a number of limitations prevent their more widespread application. Sensors are needed that can enable robots to interact and adapt to their environment. Visual sensors currently are receiving alot of attention, but force, touch, proximity, and range, should not be overlooked. Control methods are needed that can make use of this sensory information to provide coordinated manipulation in real time. There must be means for supplying, feeding, and inspecting components to be assembled. Attention must be paid to the computer modeling of manufacturing actions and their ranges of effect upon tools and work pieces, and strategy generation to deal with possible errors and variations in the process being automated.

Finally, such semi-autonomous systems should be integrated into a complete CAD/CAM system that can automatically produce a part to a customers specification in a few hours.

"Hierarchical Control Using 3-D Vision"

by

Dr. James Albus
National Bureau of Standards

This paper describes the basic theory of hierarchical control systems. A three component hierarchy is proposed: (1) a control hierarchy which decomposes tasks into subtasks; (2) a century processing hierarchy which analyses data from the external environment; and (3) a world model hierarchy which generates expectation that can be compared against observed sensory data. An implementation of this system in a microcomputer network for robot control will be described. Plans for extending this architecture to an automatic factory control system will also be discussed.